QUERCUS GARRYANA HOOK. (FAGACEAE) STAND STRUCTURE IN AREAS WITH DIFFERENT GRAZING HISTORIES

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ABSTRACT

We estimated seedling, sapling, and mature tree densities for two historically defined grazed-classes (LOW and HI) of the Mad River Ranger District, Six Rivers National Forest, CA. Using *Quercus garryana* Hook. vegetation coverages on a geographic information system and a variable probability sampling scheme, 9 oak stands were randomly selected from each grazed-class. We employed a second sampling stage by selecting 3 simple random samples of 100-m² quadrants from each of the 18 oak stands selected in the first sampling stage. We found greater seedling and mature tree densities for the HI grazed-class and greater sapling densities for the LOW grazed-class. Sapling densities were roughly double and seedling densities about 5 times mature tree densities regardless of grazed-class. We suggest that increased grazing intensity creates favorable environments for seedling survival, but may ultimately reduce the number of seedlings transitioning to the sapling size-class. Our results showing roughly 2:1 sapling to mature tree ratios indicate that *Q. garryana* regeneration is occurring on these rangelands.

The historical clearing of oak woodlands to maximize forage yield for livestock grazing or to convert to agricultural production has been well documented (Allen-Diaz and Holzman 1991; Bartolome et al. 1986; Bartolome and Standiford 1992; Muick and Bartolome 1987). Along with suburban encroachment, these land-use practices have been implicated as factors in the postulated decline of *Quercus douglasii* Hook. & Arn (blue oak), *Q. lobata* Nee (valley oak), and *Q. engelmannii* E. Greene Engelmann oak regeneration (Griffin et al. 1987; Muick and Bartolome 1985; Pavlik et al. 1991). Regeneration problems manifested as bimodal age structure biased towards seedlings and mature trees with a lack of sapling age-classes have been cited for each of the above species (Bartolome et al. 1986; Griffin 1971; Griffin 1976; Lathrop et al. 1990).

Quercus garryana Hook. has the longest north-south distribution among western *Quercus* spp. The northern range of *Q. garryana* extends onto Vancouver Island in Canada at 50°N latitude and the southern range runs into Los Angeles County at 34°N latitude (Stein 1990). The coastal range of *Q. garryana* terminates in Marin County, but it is found further south along the western slope of the Sierra Nevada in a limited and disjunct distribution.

The relationships between Northcoast *Q. garryana* populations and livestock grazing, land-use practices, and suburban encroachment have received limited attention (Griffin et al. 1987; Muick and Bartolome 1985; Reed and Sugihara 1986). Sugihara et al. (1987) defined plant community types for Northcoast *Q. garryana*-dominated landscapes and Saenz and Sawyer (1986) studied grazing effects on *Q. garryana* understory composition. Literature treating potential domestic livestock grazing effects on *Q. garryana* is limited to a statewide survey conducted by Muick and Bartolome (1987) and modeling efforts by Anderson and Pasquinelli (1984). Muick and Bartolome (1987) found no significant *Q. garryana* distribution patterns related to livestock grazing on the Northcoast. They assessed the adequacy of the existing *Q. garryana* sapling populations to replace trees lost through mortality by examining sapling to mature tree ratios on 13 Northcoast plots. Sapling to adult tree ratios were less than 1:1 for *Q. garryana* in their study, yet 75% of all individuals sampled were seedlings indicating no lack of seedling establishment, but a failure of seedlings to survive the transition to sapling size-classes.

Bolsinger (1988) assessed the age structure of *Q. garryana* by drawing inferences from seedling and

FIG. 1. Study sites located within Mad River Ranger District, Six Rivers National Forest, Humboldt County, CA.

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MADR    15 (4)
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TABLE 1. SUMMARY OF HISTORICAL GRAZING ALLOTMENT DATA USED FOR ASSIGNING SIX GRAZING ALLOTMENTS TO ONE OF TWO GRAZED-CLASSES. [1] AU = Animal unit = 1 individual.

Allotment	Mean annual [1]AU	Oak ha	Oak ha·AU^{-1}	Grazed-class
Long Ridge	88	1859	21	LOW
Norris-Green	108	1839	17	LOW
Barry Creek	109	1484	14	LOW
Soldier Creek	66	616	9	HI
Buck Mountain	91	766	8	HI
Van Duzen	166	1166	7	HI

sapling counts from systematic plots established across California. He found 45% of *Q. garryana*-type plots contained no seedlings and 38% contained no saplings suggesting the potential for insufficient replacement populations or that present spatial distributions may be shifting. Anderson and Pasquinelli (1984) predicted declining *Q. garryana* distribution under "present trend" conditions. Their model parameterized livestock grazing, wildlife pressure, fire frequency, and weather conditions specific to the Northcoast's Sonoma and Mendocino Counties.

We designed this study to describe *Q. garryana* stand structure and to examine livestock grazing intensity effects on this structure. Specifically, we sought to determine whether differentially grazed stands contained significantly different densities of seedlings, saplings and/or mature trees. This information should provide insight about the regeneration status of *Q. garryana* on California's Northcoast.

METHODS

Study site. We conducted this study June and July 1995 on the Mad River Ranger District (MRRD), Six Rivers National Forest (SRNF), and Humboldt County, CA (Fig. 1). SRNF lies within sections of Humboldt, Del Norte, Siskiyou, and Trinity Counties in the northern California coast range. MRRD is typified by a Mediterranean climate of cool, moist winters and warm, dry summers. Average January temperatures range from −2 to 4°C (28 to 40°F) and average July temperatures range from 17 to 27°C (64 to 80°F) (Oakeshott 1978). Annual precipitation ranges from 127 to 152 cm (50 to 60 in).

Eighty percent of this precipitation occurs between November and April. Miles (1993) described MRRD soils as derived from the Franciscan Melange Complex with *Quercus garryana* stands occurring predominantly on the Oxalis-Hecker-Doty association. These are well-drained, pale brown loams with moderate to strong blocky structure and a slightly acidic nature.

Grazed-classes. As an initial grazing allotment screening, we asked MRRD range personnel to identify 3 MRRD grazing allotments with high historical grazing intensity and 3 with relatively low historical grazing intensity. These allotments were to represent each of two grazed-classes (LOW or HI; Table 1). MRRD range personnel stated that each of the 3 LOW grazed-class allotments were historically grazed very lightly, and had no permitted grazing activity for 5 to 10 years prior to this study. MRRD range personnel also confirmed that historical permitted use (1950 to 1981) continued on the 3 HI grazed-class allotments after 1981.

We derived our grazed-classes by defining grazing intensities that were based on allotment-wise *Q. garryana* hectares (estimated using 1990's GIS technology) because we believed that the majority of available forage, hence grazing pressure, occurred on the oak woodland/savanna vegetation type. We used annual animal units records (1950 to 1981) and total *Q. garryana* hectare estimates for each allotment to quantify historical grazing intensities. Actual allotment-wise stocking rates were set by MRRD range managers using their assessments of suitable grazing hectares. Suitable hectares were comprised of oak savanna; coniferous forest; and small, open grassland areas known as "glades". However, Sawyer et al. (1977) described the understory layer of the Northcoast Douglas-fir—tanoak type (*Pseudotsuga menziesii* (Mirbel) Franco—*Lithocarpus densiflorus* (Hook. & Arn.) Rehder) as sparse, less developed, and dominated by shrubby *L. densiflorus* while others have confirmed this type of coniferous forest provides much less herbaceous productivity and available forage than oak woodlands (Sharrow and Leininger 1982). While glades provide excellent forage, the fraction of the allot-

ments in this type is very small. Therefore, we assumed that oak woodlands provide the bulk of forage for grazing animals and only used *Q. garryana* hectares in grazing intensity quantification.

Sampling. Assuming that the total number of seedlings, saplings, and mature trees were a function of the area of any oak stand, we employed a 2-stage sampling design consisting of a variable probability selection scheme as the 1st-stage and simple random sampling (SRS) as the 2nd-stage. Nine *Q. garryana* stands were selected from each of 2 grazed-class subsets with probability proportional to the area of the remaining *Q. garryana* stands within that particular grazed-class. Hence, larger *Q. garryana* stands had higher selection probabilities. We incorporated these probabilities, known as 1st-order inclusion probabilities (Overton and Stehman 1995), into Horvitz-Thompson (HT) estimation of the size-class densities for each grazed-class (Horvitz and Thompson 1952). We calculated sample-based sampling variance estimates for the two-stage HT estimator using the Sen-Yates-Grundy (SYG) method (Yates and Grundy 1953). This method requires that the 2nd-order inclusion probabilities for the selected 1st-stage units (*Q. garryana* stands) be known. Second-order inclusion probabilities are the probabilities that any 2 particular *Q. garryana* stands were both chosen during the selection process. We estimated 2nd-order inclusion probabilities using the list sequential method outlined by Sunter (1977). The 2nd sampling stage entailed SRS of three 100-m² quadrats from each unit (18 oak polygons) selected in the 1st stage. We then scaled seedling, sapling, and mature tree estimates from each grazed-class, deriving mean values (per 100 m²) for standardization and comparison ease. Ninety-five percent confidence intervals were constructed around each size-class density estimate for statistical comparisons.

We obtained Universal Transverse Mercator (UTM) coordinates for each point selected during the 2nd-stage of sampling from a geographic information system database. We arbitrarily decided that these UTM coordinates would serve as the southeastern corner of each 100-m² sampling quadrat. Quadrats were located in the field with a handheld geographic positioning system. We delineated boundaries of each quadrat with a handheld compass and cloth tape. Seedlings (<1 cm basal diameter), saplings (<10 cm and >1 cm basal diameter), and mature trees (>10 cm basal diameter) were enumerated for each quadrat. Definition of size-classes followed Muick and Bartolome (1987). We did not age individual seedlings, saplings, or mature trees.

We estimated several site variables at each quadrat to determine potential environmental disparities among the two grazed-classes. These variables included 1) slope, 2) azimuth, 3) canopy cover, and, 4) dominant herbaceous understory type. The sine of slope in degrees and the cosine of azimuth in degrees from N were multiplied to create a solar insolation indicator variable *northness (sensu* Borchert et al. 1989) which potentially varied from +100 to −100. Greater positive values of this variable indicate a N-facing steep slope while higher negative values indicate a S-facing steep slope. We ocularly estimated canopy cover at each site. We characterized the herbaceous understory type at each quadrat by making 6 randomly located herbaceous species cover estimates within the quadrat. Each estimate was made with a 10-point frame using the first foliar intercept criterion for each pin placement (Heady and Rader 1958). We then classified species into one of the following functional groups: 1) annual grass, 2) annual forb, 3) perennial grass, 4) perennial forb, or 5) woody perennial. Bare ground and dry organic matter 10-point frame hits were also recorded and categorized.

We estimated edaphic characteristics at a randomly chosen 1 of 3 quadrats at each of the 18 *Q. garryana* stands. Soil pits were excavated for estimation of the following variables: 1) solum depth, 2) rooting depth, 3) clay percent (by feel), 4) rock fragment percent (2-mm mesh sieve), 5) pH (LaMotte colorimetric method), 6) moist Munsell color value, 7) textural-class (by feel), and 8) available water-holding capacity (USDA 1993). Parametric tests were not performed to assess significant differences for these variables between grazed-classes, nor to correlate them to *Q. garryana* size-class estimates because they were collected with the variable probability sampling scheme described above. By definition, unequal probability samples do not meet the parametric test requirement of independent, identical distributions between groups (Sarndal et al. 1992). Therefore, we present continuous data in tabular form (Table 2) and discrete data in graphical (Fig. 2) form for grazed-class comparisons. Where tabular and graphical examination suggested differences between the grazed-classes in a given variable, we tested joint bivariate distributions with a two-dimensional Kolmogorov-Smirnov (2DKS) nonparametric procedure (Garvey et al. 1998). Two-DKS uses a bootstrapping technique (500 Monte Carlo simulations) to iteratively compare randomly derived expectation matrices with an observed joint-distribution matrix. This technique is effective at assessing both linear and non-linear relationships among bivariate distributions and makes no assumptions about functional responses.

RESULTS

Comparison of 95% confidence intervals showed that seedling and mature tree densities were greater in the HI grazed-class while sapling densities were greater in the LOW grazed-class (Fig. 3). Mean estimates are reported ± the 95% confidence interval and statistical significance determined by overlap or

TABLE 2. SAMPLE SIZE (N), MEANS, AND STANDARD ERRORS (SE) OF CONTINUOUS ENVIRONMENTAL VARIABLES FOR EACH GRAZED-CLASS. [1] Units defined in text.

Variable	n	HI		LOW	
		Mean	SE	Mean	SE
Canopy cover (%)	27	54.3	4.5	63.7	4.4
Slope (degrees)	27	17.5	1.4	26.9	1.4
[1]Northness	27	2.6	4.9	−5.7	4.6
AWC	9	4.0	0.5	4.3	0.3
pH	9	6.2	0.1	6.2	0.1
Solum depth (cm)	9	115.7	4.1	118.4	3.1
Rooting depth (cm)	9	76.2	2.0	76.2	0.7
Clay (%)	9	15.4	1.1	17.4	0.5
Rock fragment (%)	9	46.0	3.6	42.7	1.1
Moist Munsell color value*	9	3.3	0.1	3.5	0.1

not. The seedling density estimate for the HI grazed-class was 33.5 ± 3.3 seedlings per 100 m² compared to 19.1 ± 1.2 seedlings per 100 m² for the LOW grazed-class. The mature size-class followed the same trend in that the HI mature tree estimate was greater than the LOW mature tree estimate (HI = 5.0 ± 0.5, LOW = 3.9 ± 0.4). Sapling size-class density estimates were the opposite. There were on average more saplings per 100 m² in the LOW grazed-class (10.8 ± 0.3) than in the HI grazed-class (9.3 ± 1.1; Fig. 3).

The greatest disparity in environmental variables between the two grazed-classes was average slope (HI = 17.5 ± 1.4, LOW = 26.9 ± 1.4; Table 2). Other continuous variables appeared quite similar so were not analyzed further than reporting means and standard errors. Examination of the dominant herbaceous understory type standard errors (Fig. 2) indicated similar distributions of this categorical variable between grazed-classes. Soil textural-class differences were evident; all 9 LOW grazed-class sites were classified as loams while 5 of 9 HI grazed-class soils were determined to be loams with

1 clay loam and 3 sandy loams. Only 1 soil pit per site was dug, therefore no dispersion statistics were estimable from these data.

Two-DKS results indicated that the joint distributions between slope and seedling density, slope and sapling density, and slope and mature tree density (Fig. 4) were not significantly different from random (P = 0.60, 0.53, and 0.50; respectively).

DISCUSSION

Greater seedling densities coupled with lower sapling densities in areas with greater grazing intensities suggest that herbivory of surrounding vegetation may positively influence *Q. garryana* seedling survival and recruitment, but that incidental trampling and herbivory of the seedlings may discourage transition to the sapling stage. While this needs experimentation, there are experimental results for *Q. douglasii* which corroborate our inferences and may help to explain our observations. *Quercus douglasii* and *Q. garryana* are taxonomically and ecologically similar species. Both belong
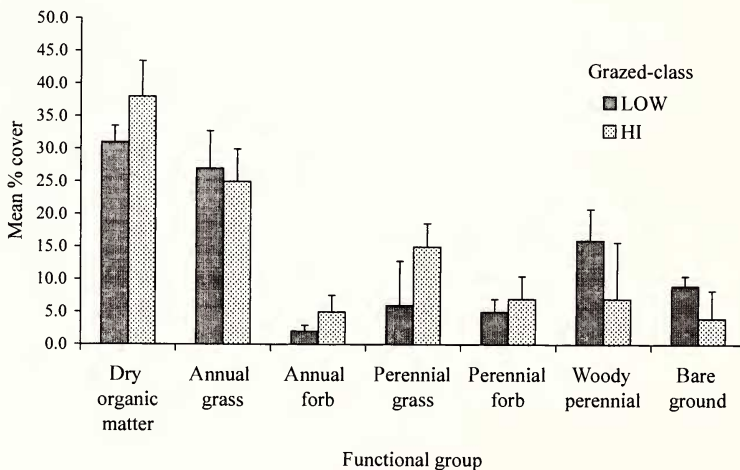

FIG. 2. Functional group cover means and standard errors (n = 9 for each grazed-class) as determined by 10-point frame estimates.
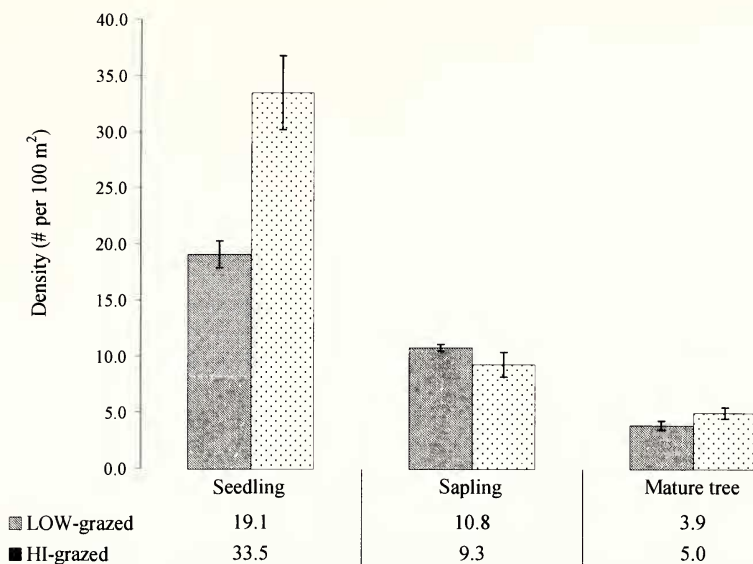
FIG. 3. Seedling, sapling, and mature tree density means and 95% confidence intervals for each grazed-class.

to the white oak subgenus *Lepidobalanus* and occupy apparently similar ecological sites—shallow, rocky hill slopes—in distinctive Californian climatic regions (Rundel 1979; Rundel 1986; Stein 1990). Additionally, these species freely hybridize along climatic transition zones (Tucker 1979).

In greenhouse experiments, Gordon et al. (1989) found greater *Q. douglasii* seedling emergence and growth responses in annual forb (*Erodium* spp.) seeded plots compared to annual grass (*Bromus diandrus* L.) seeded plots. They attributed this to increased rates of water stress in the annual grass plots. This illustrates that competition between *Q. douglasii* seedlings and neighboring herbaceous vegetation does occur, however, Gordon et al. (1989) obtained their results absent defoliation. Welker and Menke (1990) reported that defoliation of annual vegetation surrounding growing *Q. douglasii* seedlings was beneficial in reducing evapotranspiration of competing vegetation, thereby reducing the rate at which the *Q. douglasii* seedlings

encountered water stress. These results offer potential explanations for our findings, whereby herbivory is releasing *Q. douglasii* seedlings from resource competition with surrounding vegetation. Resources being competed for are probably water, nutrients, and space. However, this phenomenon is likely overwhelmed at higher grazing intensities where grazing selectivity lessens and seedlings are depredated more or less incidentally.

Hall et al. (1990) showed that at very high stocking rates, where animals are actually competing for space as well as forage, increased seedling depredation rates occurred. However, with reduced stocking rates, Hall et al. (1990) found little to no livestock preference for *Q. douglasii* seedlings. Given their similarities, these results likely hold for *Q. garryana*. Seedling depredation is probably a function of forage production and availability, rodent populations (Davis et al. 1990), and stocking rate. Experimental evidence for *Q. garryana* is needed.
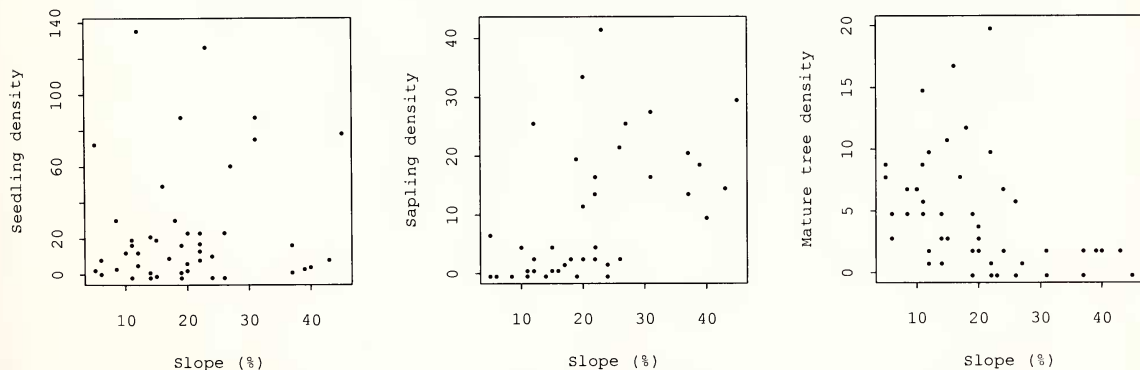

FIG. 4. Joint bivariate distributions of slope and seedling density, sapling density, and mature tree density.

We did not measure microtopographic relief or estimate soil disturbance, but these factors may be important reasons for higher seedling densities. Because livestock grazing creates soil disturbance (Kauffman and Krueger 1984), areas of higher grazing intensity tend to have greater micro-relief and therefore a higher probability of radicle interception and penetration with the soil (Watt 1919).

During autumn months, *Q. garryana* dormancy decreases interspecific competition for light and water between annual grasses and *Q. garryana* seedlings (Hibbs and Yoder 1993). This reduction in photosynthesis and growth allows seedling underground biomass persistence and promotes carbohydrate storage in root systems (Hibbs and Yoder 1993) while the annual grasses dominate available resources. Domestic stock grazing in the spring results in annual grass defoliation as well as the incidental *Q. garryana* seedling defoliation and trampling. However, Hibbs, and Yoder (1993) have shown that *Q. garryana* is a prolific and adventitious sprouter. They found 20-year-old *Q. garryana* seedling roots with aboveground shoots less than 3 years in age. Hence, should the *Q. garryana* seedling survive defoliation and water stress until annual grasses have been grazed or completed their life cycle, the *Q. garryana* seedling taproot and fine root system can eventually access resources at lower soil depths where annual grasses are not competing. Indeed, we usually found a dense network of fine *Q. garryana* roots dispersed throughout the solum to a depth of $75+$ cm (Table 2), while annual grass roots were not observed below the surface 10-cm. Seedlings able to establish these deeper roots should increase their survival chances via resource partitioning (*sensu* Brown 1998). However, resource partitioning is likely not achieved until *Quercus* seedlings have successfully negotiated interspecific resource competition mediated by cattle dietary preferences for herbaceous grasses and forbs. Coupled with an ability to survive many seasons of foliage removal via sprouting, resource partitioning may account for greater *Quercus* seedling densities in areas with higher grazing intensities.

Litter decomposition rate is another potentially important factor that may be differentially treated across grazing regimes. Desiccation is a major cause of germination failure in California's predominantly dry oak woodlands (Borchert et al. 1989). However, the consistently moist, but cool Northcoast environs are more likely to result in low decomposition rates leading to higher litter accumulation with a concomitant increase in acorn rot. Opening of the herbaceous layer to increased solar insolation via phytomass removal by livestock may reduce the potential for acorn rot, thereby increasing germination and seedling success. These hypotheses all need *in situ* experimental testing in *Q. garryana* stands.

Significantly greater mature tree densities in the HI grazed-class may be the best explanation for both greater seedling densities and lesser sapling densities in this group. It follows that more trees lead to more acorns leading to more seedlings. Transition from seedling to sapling is probably inhibited by lack of sufficient light and other resources due to crowding by mature trees combined with seedling defoliation and depredation by livestock. Allen-Diaz and Bartolome (1990) concluded that while recruitment of *Q. douglasii* seedlings was frequent, none of their seedlings made the transition into sapling size-classes.

Why was mature tree density greater in the HI grazed-class? The HI-grazed allotment group was generally found on gentler slopes that may have had some indirect effects on sapling to mature tree transition. For example, fires are known to burn less intensively on gentler slopes (Albini 1976) which might have provided a more favorable environment for tree development. Alternatively, deeper soils on sites with gentler slopes may have provided a microclimate more conducive to sapling to tree transition. However, our soil data revealed no evidence for this. Examination of maps and field observation revealed no obvious geomorphological or topographical patterns that might account for these differences.

Aside from the grazed-class comparisons of size-class densities, our results indicate that natural *Q. garryana* regeneration on these MRRD sites is not at risk. Representing roughly double the mature tree stock, densities of about 10 saplings per 100 m^2 seems a surplus. Should one tree from a well-stocked stand die at any given time, several saplings should be available for replacement. To truly assess regeneration status, mortality and survival rates between each size-class must be known. Our single season study did not permit estimation of mortality rates even for seedlings. Our point-in-time estimates of age structure do provide compelling evidence that regeneration of this species is occurring. Annual assessment of seedling mortality rates coupled with creative techniques for estimating sapling to tree transition probabilities and tree mortality rates are needed to verify our results and quantify the regeneration status of this resource.

CONCLUSIONS

Higher seedling but lower sapling densities with increased grazing intensity indicates that grazing at higher stocking rates does not affect *Q. garryana* seedling recruitment. There seems to be plenty of seedlings beneath and around tree canopies, but seedlings in the higher grazed areas are making the transition to the sapling size-class in lesser numbers than those in the more lightly grazed areas. However, our results indicate that *Q. garryana* regeneration is potentially occurring regardless of grazing pressures as evidenced by the roughly 2:1 sapling to tree ratio estimates found for both grazed classes.

LITERATURE CITED

ALBINI, F. A. 1976. Estimating wildfire behavior and effects. USDA Forest Service, Intermountain Forest and Range Experiment Station. GTR-INT-30.

ALLEN-DIAZ, B. AND J. W. BARTOLOME. 1990. Survival of *Quercus douglasii* (Fagaceae) seedlings under the influence of fire and grazing. Madroño 39:37–53.

ALLEN-DIAZ, B. H. AND B. HOLZMAN. 1991. Blue oak communities in California. Madroño 38:80–95.

ANDERSON, M. V. AND R. L. PASQUINELLI. 1984. Ecology and management of the northern oak woodland community, Sonoma County, California. MA thesis. Sonoma State University.

BARTOLOME, J. W., P. C. MUICK, AND M. P. MCCLARAN. 1986. Natural regeneration of California hardwoods. *In* T. R. Plumb and N. H. Pillsbury (eds.), Proceedings of the symposium on multiple-use management of California's hardwood resources, Nov. 12–14, 1986; San Luis Obispo, CA. Pacific Southwest Forest and Range Research Station.

BARTOLOME, J. W. AND R. B. STANDIFORD. 1992. Ecology and management of Californian oak woodlands. *In* P. F. Ffolliott et al. (eds.), Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico, April 27–30, 1992; Sierra Vista, AZ. USDA Forest Service GTR RM-218.

BOLSINGER, C. 1988. The hardwoods of California's timberlands, woodlands, and savannas. USDA Forest Service Resource Bulletin. PNW-RB-148.

BORCHERT, M. I., F. W. DAVIS, J. MICHAELSEN, AND L. D. OYLER. 1989. Interactions of factors affecting seedling recruitment of blue oak (*Quercus douglasii*) in California. Ecology 70:389–404.

BROWN, C. S. 1998. Restoration of California Central Valley grasslands: applied and theoretical approaches to understanding interactions among prairie species. Ph.D. dissertation. University of California, Davis, CA.

DAVIS, F. W., M. BORCHERT, L. E. HARVEY, AND J. C. MICHAELSEN. 1990. Factors affecting seedling survivorship of blue oak (*Quercus douglasii* H. & A.) in Central California. *In* R. Standiford (ed), Proceedings of the Symposium on oak woodlands and hardwood rangeland management, Oct. 31–Nov. 2, 1990, Davis, CA. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

GARVEY, J. E., E. A. MARSCHALL, AND R. A. WRIGHT. 1998. From star charts to stoneflies: Detecting relationships in continuous bivariate data. Ecology 79: 442–447.

GORDON, D., J. WELKER, J. MENKE, AND K. RICE. 1989. Competition for soil water between annual plants and blue oak (*Quercus douglasii*) seedlings. Oecologia 79:533–41.

GRIFFIN, J., P. MCDONALD, AND P. MUICK. 1987. California oaks: a bibliography. Pacific Southwest Forest and Range Research Station. GTR-PSW-96.

GRIFFIN, J. R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862–68.

GRIFFIN, J. R. 1976. Regeneration in *Quercus lobata* savanna, Santa Lucia Mountains, California. American Midland Naturalist 95:442–85.

HALL, L., M. GEORGE, T. ADAMS, P. SANDS, AND D. MCCREARY. 1990. The effect of season and stock density on blue oak establishment. *In* R. Standiford (ed), Proceedings of the symposium on oak woodlands and hardwood rangeland management, Oct. 31–Nov. 2, 1990; Davis, CA. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

HEADY, H. F. AND L. RADER. 1958. Modifications of the point frame. Journal of Range Management 11:95–96.

HIBBS, D. E. AND B. J. YODER. 1993. Development of Oregon white oak seedlings. Northwest Science 67: 30–36.

HORVITZ, D. AND D. THOMPSON. 1952. A generalization of sampling without replacement from a finite universe. Journal of the American Statistical Association 47: 663–685.

KAUFFMAN, J. B. AND W. C. KRUEGER. 1984. Livestock impacts on riparian ecosystems and streamside management implications: a review. Journal of Range Management 37:430–438.

LATHROP, E., C. OSBORNE, A. ROCHESTER, K. YEUNG, S. SORET, AND R. HOPPER. 1990. Size class distribution of *Q. engelmannii* on the Santa Rosa Plateau, Riverside, California. *In* R. Standiford (ed), Proceedings of the symposium on oak woodlands and hardwood rangeland management, Oct. 31–Nov. 2, 1990; Davis, CA. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

MILES, S. 1993. Soil survey of Six Rivers National Forest area: USDA Soil Conservation Service, Pacific Southwest Region.

MUICK, P. AND J. BARTOLOME. 1987. An assessment of natural regeneration of oaks in California. California Division of Forestry. Contract# 8CA42136.

MUICK, P. AND J. W. BARTOLOME. 1985. Research Studies in California related to oaks. Wildland Resources Center, University of California, Berkeley. Report No. 7.

OAKESHOTT, G. 1978. California's changing landscapes: a guide to the geology of the state. New York: McGraw-Hill Book Company.

OVERTON, W. S. AND S. V. STEHMAN. 1995. The Horvitz-Thompson theorem as a unifying perspective for probability sampling: with examples from natural resource sampling. The American Statistician 49:261–268.

PAVLIK, B., P. MUICK, S. JOHNSON, AND M. POPPER. 1991. Oaks of California. Los Olivos, CA: Cachuma Press, Inc.

REED, L. AND N. SUGIHARA. 1986. Prescribed fire for restoration and maintenance of Bald Hills oak woodlands. *In* T. R. Plumb and N. H. Pillsbury (eds.), Proceedings of the symposium on multiple-use management of California's hardwood resources, Nov. 12–14, 1986; San Luis Obispo, CA. Pacific Southwest Forest and Range Research Station.

RUNDEL, P. W. 1979. Adaptations of mediterranean-climate oaks to environmental stress. *In* T. R. Plumb (ed.), Proceedings of the symposium on the ecology, management, and utilization of California oaks, June 26–28, 1979; Claremont, CA. Pacific Southwest Forest and Range Research Station.

RUNDEL, P. W. 1986. Origins and adaptations of California hardwoods. *In* T. R. Plumb and N. H. Pillsbury (eds.), Proceedings of the symposium on multiple-use management of California's hardwood resources, Nov. 12–14; San Luis Obispo, CA. Pacific Southwest Forest and Range Research Station.

SAENZ, L. AND J. O. SAWYER. 1986. Grasslands as compared to adjacent *Quercus garryana* woodland understories exposed to different grazing regimes. Madroño 33:40–46.

SARNDAL, C., B. SWENSSON, AND J. WRETMAN. 1992. Model Assisted Survey Sampling. Springer-Verlag, New York, NY.

SAWYER, J. O., D. A. THORNBURGH, AND J. R. GRIFFIN. 1977. Mixed evergreen forest. *In* M. J. Barbour and J. Major (eds.), Terrestrial vegetation of California. John Wiley and Sons, New York, NY.

SHARROW, S. H. AND W. C. LEININGER. 1982. Forage preferences of herded sheep as related to brush control and seasonal browsing damage to Douglas-fir regeneration. Oregon Agricultural Experiment Station. Project #0066.

STEIN, W. I. 1990. *Quercus garryana* Dougl. ex Hook. Oregon white oak. *In* R. M. Burns and B. H. Honkala (eds.), Silvics of North America: hardwoods. USDA Forest Service, Washington, DC.

SUGIHARA, N. G., L. J. REED, AND J. M. LENIHAN. 1987. Vegetation of the Bald Hills oak woodlands Redwood National Park, California. Madroño 34:193–208.

SUNTER, A. 1977. List sequential sampling with equal or unequal probabilities without replacement. Journal of Royal Statistical Society; Series C 26:261–268.

USDA. 1993. Soil Survey Manual: Agricultural Handbook No. 18. U.S. Dept. of Agriculture: For sale by the Supt. of Docs., U.S. G.P.O., Washington, DC.

WATT, A. S. 1919. On the causes of failure of natural regeneration in British oakwoods. Journal of Ecology 7:173–203.

WELKER, J. AND J. MENKE. 1990. The influence of simulated browsing on tissue water relations, growth and survival of *Quercus douglasii* (Hook and Arn.) seedlings under slow and rapid rates of soil drought. Functional Ecology 4:807–17.

YATES, F. AND P. GRUNDY. 1953. Selection without replacement from within strata with probability proportional to size. Journal of the Royal Statistical Society; Series B 15:235–61.